PASSIVE COOLING POTENTIAL OF A SUITE OF RETROFITS FOR OLDER LOS ANGELES HOUSING WITH SIGNIFICANCE FOR POLICY

by
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Abstract

Four retrofits to older housing are examined: cool roofs, window overhangs, window films and shade trees. The potential of these measures to lower the temperature inside homes in Los Angeles is evaluated through literature review. An energy simulation, modeling these retrofits is attempted. Typical costs of the retrofits are gauged. The review concludes that passive cooling retrofits have been under appreciated as a possible remedy for heat stress, and as an alternative to air conditioning. Some implications for policy are examined and guidelines for action recommended.

Table of Contents

Introduction.

Los Angeles is already very hot during heat waves, and the heat extremes that we expect with climate change intensify and multiply the risk of heat illness. By 2050, residents of Los Angeles may experience 29 extra days of heat index above 105º F annually.[1]

Yet 29 percent of homes in Los Angeles do not have air conditioning.[2] Los Angeles has five narrow climate zones that lie like stripes across the map. That means there are significant differences in temperature, aridity and vegetation over small distances. In 2017, researchers examining the prevalence of air conditioning found 40 percent of households in the hotter San Gabriel and San Fernando valleys do not have air conditioning, but in the Los Angeles basin and near the coast, more than 70 percent do not have it.[3]

By the year 2050, it is predicted that there will be more than twice as many heat wave exposure cases in California as now.[4] But even more people will try to endure the heat illness at home. The number who suffer serious health consequences at home may be an order of magnitude larger than those who seek medical help.[5] Heat is the largest cause of death from weather events in the United States. It takes more lives than flooding and hurricanes combined.

When a person overheats, the body attempts to transfer heat from the core to the periphery, increasing blood flow to the skin. Skin blood vessels dilate and blood pressure drops. To avoid the reduction in blood pressure, the heart beats faster and harder, if it can. In elders and others whose hearts are already working at capacity, the drop in blood pressure cannot be avoided, and the brain may get insufficient oxygen.[6] Children have a strong ability to pump blood to their extremities, but their sweat glands are underdeveloped, and they are often more physically active. This gives them “great vulnerability to thermal injury.” [7]

In addition to the young, old, and infirm, among those most at risk for heat illness are those who cannot afford to install air conditioning, or who must ration it to pay the electric bill. Shutoffs for inability to pay are not rare. Southern California Edison, one of two main electric utilities for Southern California, disconnected power for approximately 408,000 households for non-payment in 2017.[8] This does not include shutoffs by Los Angeles Department of Water and Power (but it does include some areas outside Los Angeles County).

In one survey in Phoenix, 36 percent of respondents had foregone air conditioning due to cost. An additional 6 percent said their air conditioner was broken. Thirty-eight percent said they felt too hot inside their homes. Renters and Latinos were significantly more likely to experience this.[9] Heat is an environmental justice issue.[10]

There is no official estimate yet for the number of people at risk for heat stress in Los Angeles. However, an analysis of data contained within the California Heat Assessment Tool indicates 107,314 people live in 29 census tracts the county has deemed to be a high priority for heat vulnerability.

To avoid heat stress during heat waves, people need to cool their bodies at night. If temperatures remain high and if humidity is high at night, and if people in a region are not accustomed to this heat, which is the case in southern California, then they are at higher risk for heat stress. As part of an analysis for Climate Smart Cities in 2018, the Trust for Public Land created this map, Figure 1, by combining data from MODIS and LANDSAT images of nighttime hotspots.

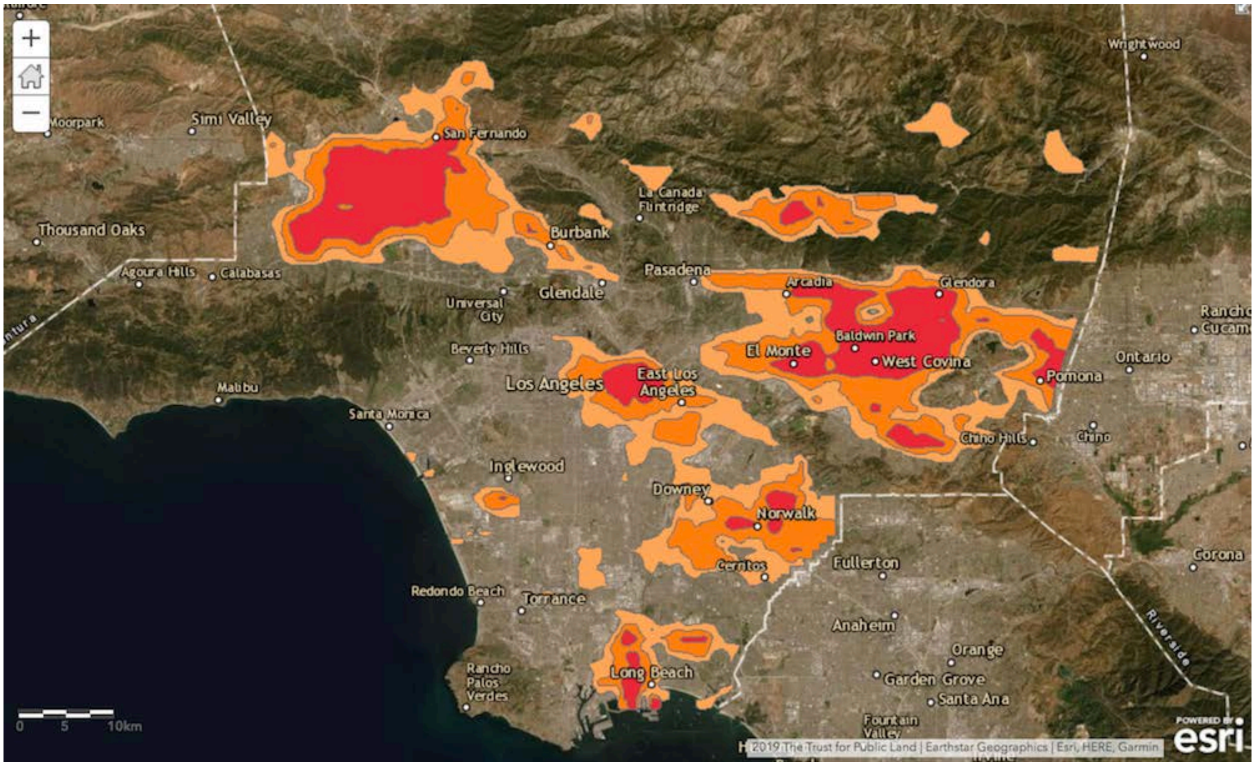

Figure 1.Nighttime heat measured by satellite sensors. Trust for Public Land. 2018.

Given the heat that is to come, the heat illness that some residents already experience, and the difficulty of paying for air conditioning and its carbon cost, this paper will look at the possibility of making homes more comfortable without installing air conditioning.

It is important to note that much of the older housing in Los Angeles is not particularly well built and is often uninsulated. This is likely related to the historically mild climate. The lack of severe weather meant relatively low consequences for construction that elsewhere, might not have been acceptable.

When a home is carelessly built, it is not very suitable for air conditioning, even though it may have it. That is because heat can easily seep in from outdoors. The air conditioner is thus continually cooling air additional to that which is drawn in through its intake. In this situation it will frequently cycle, cooling the home, which then quickly heats up again, then cooling it again. This causes higher electricity bills, more fossil fuel use (to the degree that the grid is running fossil-based electricity), and further use of refrigerant. Most common refrigerants are extremely high in their global warming potential (GWP), typically 2800 times worse for the atmosphere than carbon dioxide.

This paper then seeks to answer: *By what amount can one reduce the temperature in a home without air conditioning, applying a package of four physical changes: Window films, window overhangs, shade trees and a "cool roof"? What would be the associated costs?*

Throughout the paper these will be referred to as the four retrofits. The hypothesis is that a package of targeted retrofits can reduce or eliminate the need for air conditioning in some areas of Los Angeles.

Methods.

Literature Review.

Three of the four retrofits chosen here involve technology that advances over time. For these three, solar films, overhangs and cool roofs, a thorough search of the recent scientific literature was undertaken. For research on the fourth, shade trees, no emphasis was placed on publication date because tree research was deemed to be equally applicable regardless of period. Priority was also placed on studies where researchers took measurements or modeled the temperature of indoor air. Most researchers did not study this. Rather, they study and report units of reduced energy use, either in kilowatt-hours or percentage decrease. Where results were expressed in temperature, those measurements are usually taken outdoors, not the focus on this paper. An attempt is made to find all recent studies where indoor temperature was measured.

Plan for Data Analysis.

Several software simulation programs exist to model energy efficiency in buildings. However, none allows for evaluation of all four retrofits or adaptations addressed here. Some software does not allow the user to model overhangs (ENVI-met), but does allow for trees. One well-respected software, EnergyPlus, is not geared for residential queries, but instead for commercial and industrial simulations. The platform BEopt, which operates on the EnergyPlus physics engine, was created to address this shortcoming. But the EnergyPlus platform underlying BEopt does not allow for modeling trees. This deficiency in the simulation tools has been noted. Pastore et al. write, "Although indoor comfort and building energy performance simulations have been acquiring increasing importance, simulation tools still tend to be disconnected from elements that characterize the surrounding environment, such as the presence of vegetation…" [11] Notwithstanding these limitations, a simulation with BEopt was attempted as the best option.

First a location in Los Angeles was chosen. The map at Figure 1, plus recent studies, indicate that one part of Los Angeles that already experiences stress during heat waves, and is predicted to experience disproportionately more, is Boyle Heights.[12] Boyle Heights has been noted as one of Los Angeles' small pockets for high heat vulnerability at night.

Weather data from the California Energy Commission Climate Zone 9 was chosen and uploaded, corresponding to this neighborhood.

An older home was created for the model. In 2016, sixty-one percent of California existing housing stock had been built before 1980.[13] Older homes are less efficient, having been built before California's energy efficiency standards in Title 24 of the state code were enacted in 1975. A compelling map in Nahlik et al. illustrates the extent to which Los Angeles County is covered in single family housing constructed prior to 1960.[14]

A model of a 1500 ft^2 home was constructed in BEopt. The streets in Boyle Heights run at 45° to the cardinal directions. Therefore, one model was created facing northeast, and another southwest. Parameters were input, indicating no insulation, single-pane windows, concrete foundation wall, no roof overhang, plus standard roof, siding, wall and floor materials.

Second, an identical building was constructed adding the three proposed retrofits that are available in BEopt: overhangs over the south and west-facing glass, solar spectrally-selective window films, and a white reflective roof. Specifically, the model was instructed that solar films reducing 50 percent of incoming solar radiation were applied in this design case.

A parametric analysis was run comparing the two reference as-is models against two houses on which the three available retrofits were made. The output was designated to be internal air temperature. An analysis of any differences in peak temperature; hour when peak temperature was reached; and average temperature, by number of days, was also attempted.

Literature Review.

The literature for each of the four types of retrofit is reviewed in turn.

Window Films.

Heat gain through a window can be 10 to 20 times greater per square area than through exterior walls. This highlights the importance of controlling this source of heat gain.[15]

Most studies of window films do not involve residential buildings. No research is found regarding window films as a cooling retrofit for existing California residences. Instead, the driver for much research on solar window films has been the rapid buildout of glass office buildings internationally, sometimes with little thought to the attendant air conditioning requirements. Scientists have noted the limits of the existing research.[16]

Solar radiation reaches Earth and its buildings in a range of wavelengths. Relevant to glazing, these wavelengths can be divided into visible light, 0.38–0.76 microns (360-760 nm), and infrared, between 0.76–3.5 microns. (760-3500 nm) The infrared portion of sunlight significantly increases the cooling needs of a building. [17]

At least three properties affect the thermal behavior of glass (and glass covered by film): its transmittance, its absorptance, and its reflectance.[18] Films work by adhering new properties to the window, thus changing how it responds to different wavelengths. Physics texts state that:

$$\alpha(\lambda) + \rho(\lambda) + \tau(\lambda) = 1$$

where α is absorbtance, ρ is reflectance and τ is transmissivity or transmittance. Emissivity, which is sometimes given, has the same value as absorbtance.[19]

Solar films are readily available commercial products that can be applied, sometimes even by a lay person, to the inside or the outside of windows. Generally engineers of films design them to allow visible light to pass through, but reflect away UV and infrared wavelengths, which carry a lot of heat. Often this is accomplished by means of nanolayers of metals or semiconductors dispersed in the film.[20]

One challenge is that different properties of glass may be desired at different times of year or day on a single building. Thermal radiation may be unwanted in hot weather, but desirable in cold weather. Researchers find that when they do year-round research, that in winter, the most advantageous results are sometimes found on their control windows that have no film, because these admit more of the sun's rays.[21] In other words, there is a winter penalty for the summer improvements from window films.

The need for sophisticated coatings that address this complexity has led to the development of smart windows, including gasochromic, electrochromic and liquid crystal coatings and layers, which allow windows to respond to changing light and thermal conditions. Among these developments, electrochromic devices are so far the most common. They consist of a thin film that is "sandwiched between two layers of glass and changes from clear to coloured, and back again, in response to a short electric impulse." [22] But these are still relatively new, not widely commercially available for residential situations, and prohibitively expensive.

In the meantime, less-sophisticated solar window films can effectively block heating radiation and can lower temperatures. Especially in moderate or hot climates, these can be applied to existing buildings to change their thermal properties.[23]

Pereira et al., in research in the temperate climate of Lisbon, compared offices with and without window films. They found an 86 percent reduction in cooling energy use in the office with solar film applied. The balance was favorable, even taking into account the decrease in winter sun admitted.[24] They measured a reduction at peak of 4.8°C (8.6°F) on a July day. Using an outdoor film, her team saw even greater summer temperature reductions, 8.9°C (16° F). Average reductions on the July days were 2.8°C (5°F), and with the outdoor film, 4.1°C (7.4°F).

Moretti et al. reported reductions in indoor temperature of 2-3°C (3.6–5.4° F) and reductions in cooling demand of 29 percent in experiments conducted in springtime.

Hui and Kwok, studying office buildings at a lower latitude, 22°, in Hong Kong, found their strongest cooling with window films on east and west facing windows, where they found most heat was gained in summer. "If a building has unshaded clear glazing on the east, west or south sides, then adding window film will most likely result in considerable energy savings. For reducing cooling costs, priority should be given to west or east facing windows," they wrote. [25]

Overhangs.

This section reviews research on fixed overhang structures, specifically, architectural pieces permanently anchored to the wall above windows, on the outside. Since these lie on or near the horizontal plane, they prevent sunlight from striking and penetrating the window in the first place. The concept was well understood by ancestors on different continents who employed deeply inset windows in adobe buildings, or deep roof overhangs. But roof overhangs and deeply inset windows are part of the original design of a building, whereas here we seek relatively inexpensive options that may be possible to add to a residence some 80 years after construction. Such overhangs are beginning to be commercially available, but the rediscovery of this adaptation as an option for retrofit is still in its infancy.

Literature that evaluates overhangs for the purpose of cooling, and that reports results in indoor temperature reduction, is scarce. Overhangs have been found to be effective in reducing energy use. Overhangs may be made of metal, or with metal brackets supporting a lighter synthetic material, or wood. They may be solid or slatted. The literature is still insufficient to compare these different forms.

Figure 2. Commercially available window overhangs.

Using a mathematical Fourier series to calculate the effect of shading on a building in India, Kumar et al. found a decrease in the indoor temperature of 2.5°C to 4.5°C (4.5° to 8.1°F) when overhangs were modeled.[26]

According to Kamal, "simple fixed overhangs are very effective at shading south-facing windows in the summer when sun angles are high. However, the same horizontal device is ineffective at blocking low afternoon sun from entering west-facing windows during peak heat gain periods in the summer." [27]

Porritt conducted a comparison of several types of movable and fixed shading devices, retrofitted onto housing in the UK, following the 2003 heat wave in Europe that killed more than 50,000 people. He found fixed shading reduced the number of uncomfortable degree-hours by 15-16 percent for one home, and up to 28 percent on another.[28]

Sghiouri et al. studied the installation of overhangs in three climates in Morocco and found overhangs were not sufficient to bring rooms into a comfortable temperature zone. But they did improve occupant comfort in all climates.[29] He concluded, “the use of external shading devices is one of the most effective strategies,” for reducing the need for cooling in hot climates.

Ebrahimpour found in a residential retrofit in Iran, that installing an overhang plus an adjoining vertical side fin to the outside of windows could yield the same reduction in solar heat gain as the installation of double pane windows, at less cost.[30]

In a study that asked similar questions to those asked here, seeking ways to increase comfort and health in poor, overheated housing in tropical Uganda, researchers Hashemi and Khatami found window shading was not effective. Sun angles in the tropics are high all year long. They concluded they had underestimated the importance of heat gain though the roof. They adapted their methods and realized substantial temperature declines once the roof was shaded.[31] This shows the importance of understanding latitude and sun angle before designing a retrofit.

Many researchers who study overhangs also studied indoor blinds and outdoor shutters. While this is outside the scope of the present paper, it is worth noting that several found strong improvement with shutters. At the same time, two teams issued cautions about indoor blinds. Indoor blinds can help with heat that comes through windows from the sun, but “internal window shading devices cannot prevent some of the solar radiation being trapped inside the room and converted to long wave radiation.” [32]

Carletti et al. also state that external shading devices outdoors are much more effective than drapes, roller blinds or venetian blinds indoors, since “they intercept and reduce incident solar radiation before it passes through the glass panes, preventing therefore greenhouse effect taking place within the house spaces." [33]

Shutters are not traditional in southern California architecture. Perhaps this is because there has been little bad weather to keep out. Since they are rare, shutters were not considered as one of the retrofit options here. However, shutters may bear consideration. Porritt found that for south and west-facing rooms, the best cooling retrofit for windows was outdoor shutters. Overhangs also substantially lowered the number of uncomfortable hours, but shutters were even more effective.

In a careful study that compared two typical residences, Pisello affixed sensors to a set of dark shutters, inside and out, then compared those temperatures with a set of shutters painted reflective white. The air temperature inside the white-shuttered room was approximately 2°C (3.8°F) cooler than the dark-shuttered room.[34] If shutters were to be contemplated as a retrofit option, they hold the advantage that the occupant may open them in winter, to capture all desired incoming solar warmth and light.

Trees.

Trees as a way to ameliorate indoor heat are relatively inexpensive and come with several benefits, among them cleaner air, carbon dioxide uptake, habitat for nature, reduced outdoor temperature and the psychological benefit of proximity to trees.

As with the other changes or retrofits looked at here, most researchers do not study the relationship between shade trees and indoor temperature. Rather, they report units of reduced energy use, either in kilowatt-hours or percentage decrease. Where results were expressed in temperature, the measurements were made outdoors.

An exception is McPherson, whose extensive work on the benefits of tree shading in California dominates the literature for the region. In one early work in Utah, he built two scale model homes on wheels, in order to experiment with different tree positions and proximities and the relationship to indoor temperature.[35] He began with a dense canopy tree, Norway maple. Trees planted on the east side of the buildings lowered peak indoor temperature, compared to the control (with no shade) by 3.25ºC (5.85ºF). For west-planted trees, the unshaded model reached its hottest point at 7:00 pm, at 32ºC (89.6ºF). At that moment, the shaded model was 6.5ºC (11.7ºF) cooler. Nor did the shaded building ever reach as high a peak temperature, only 28.5º (83.3ºF) at 3:00 pm. By the time the full-sun model was at its hottest, the shaded one had already cooled significantly.

In this study, McPherson also compared the performance of a dense shade tree, which transmitted only 10 percent of solar radiation, with a less-dense canopy, a Honey Locust, which transmitted 28 percent. The more densely-shaded house model had a peak temperature 3ºC (5.4ºF) lower than the less densely shaded house. McPherson concluded, “full shade from both dense and open canopy trees effectively lower inside temperatures.”

Pastore et al. used both data modeling and energy simulation software to see how effectively trees could control indoor and outdoor comfort. Her team studied a five-story apartment building. Results differed between the four lower floors and the highest floor, which has the roof.[36] They found that trees could reduce indoor temperatures by as much as 3.4ºC (6.1º F).

Pastore examined the effects of leaving windows open or closing them, and again. the results differed depending on whether the apartment had a roof or was on a lower floor. The shaded top floor apartment was cooler with windows left open, whereas other shaded floors were cooler if windows were closed. This may be relevant to single story homes in Los Angeles, since the roof will influence indoor temperatures via its significant potential heat gain.

Szkordilisz et al. did the first study of indoor cooling using shade trees in Hungary (at 47° latitude).[37] They obtained modest reductions in indoor temperature, studying several tree species, with the greatest reduction only 0.6° C (1.1°F). They concluded that transmissivity of the tree and the size of the canopy is important for more temperature reduction. Their highest results were with the species Common Hackberry (Celtis occidentalis), which is one of the recommended species on the California Climate Trees website.

In the United Arab Emirates (latitude 23°, a significantly lower latitude than southern California), in a comparison of shaded and unshaded buildings in the extreme temperatures of Al-Ain city, Haggag et al. measured a peak 12° C (21.6° F) reduction in indoor temperature using tree-shading.[38] An important finding was that the unshaded building heated up to its peak temperature much faster, reaching it at 2:00 pm versus 8:00 pm for the shaded building. This translates to many more hours of thermal comfort for occupants. Also notable is that while the shaded building cooled off faster at night, it did not fall to as low a temperature as the unshaded building. Haggag noted there were increased hours of comfort and far less demand for air conditioning. But the trees alone did not deliver an acceptable temperature.

Morakinyo et al. used both measurement and simulation to compare two similar buildings on a university campus in Nigeria (9° latitude), one shaded and one unshaded. Indoors, the results were very modest, with temperatures in the heat of the day, at 5:00 pm, brought down only 0.9–1.1°C (1.6–2°F) by the trees, to 29.8°, 31.1° and 32.3°C in September, October, and November (85.6, 88, and 90.1°F).[39]

They also looked at how much the trees cooled the air just outside the buildings. There the result was dramatic. Outside, the trees brought the temperature down by as much as 24.5ºC (44.1ºF) in September. In California, McPherson has also found that outdoors, trees may lower air temperatures 3°C (5°F).[40]

Indoors, the energy savings in buildings from tree-planting come via three main mechanisms: lowering the amount of sun-energy that reaches the built environment; trees' ability to convert water into water vapor, removing significant energy from the air through the latent heat of evaporation, and perhaps, surprisingly, wind speed reduction, which reduces the infiltration of hot air from outside to inside.[41]

There is considerable discussion about the proper placement of shade trees. For southern California, some researchers note that the ideal location for cooling shade trees is on the west side of a house, so that their shadow falls on the building in late afternoon. Late afternoon and early evening are when both air temperature and air conditioning use are highest.

Trees planted on west sides of houses had 50 to 100 percent greater savings in peak energy use than east-planted trees.

Some studies have said that trees planted on the south side of buildings will not be beneficial from the standpoint of shade, because hot temperatures during summer can come when the sun is almost directly overhead at midday and casts little shadow.[42]

The density, optimally, of a shade tree, is transient, with the canopy at its fullest when it able to block the most unwanted solar rays, yet fading away in winter when sun can warm the building and reduce the need for mechanical heating. But that deciduous habit is not a given in southern

California. Unlike trees in many parts of the United States, trees native to Southern California begin to grow in November, when the rains traditionally came. Thus, we see that a tree species must jump through several hoops to both contribute to shade cooling, yet also be a good fit for the depleted Los Angeles ecosystem. For this reason, some tree experts believe that in choosing trees for shading and climate adaptation, it is less important that species be native. Native species may not even be adapted to climate change.[43]

There is also disagreement about the effects of tree-shading in winter. As mentioned, heat gain in winter is often desirable. In studies in winter in Alabama, Pandit found 6.3 percent higher electricity use in homes with tree shading. Yet others have found that the ability of trees to slow the air currents, can reduce heat loss from buildings in winter, the same way one's body remains hotter in the absence of a breeze.

Reflective roofs.

There is now general agreement that in warm sunny climates, certain roof surfaces can lower the temperature in houses and other buildings. Cool roofs are highly reflective of the sun's radiation. Alternatively, the roof may have the property of absorbing radiation, and reradiating it out at a different wavelength.

As with the other measures studied, most cool roof studies tended to measure the reduction in household energy use, rather than change in indoor temperature. Studies find these buildings use less energy. Yet within that general understanding, there are important details.

In recent research, teams have found that the amount of benefit obtained from a cool roof sometimes relates to the amount of ceiling or roof insulation.[44] Looking at several climate zones worldwide, Piselli et al. find the optimal cool roof will have no more than 0.03 m (1.2") of insulation, and will reflect 80 percent of the sun's energy (0.8 reflectance). The team finds that insulation largely determines the effectiveness of the cool roof. They make the striking observation that the "classic approach of super-insulated buildings should be reframed," for all but the hottest and coldest climates.[45]

Another team notes that in Italy, the construction practice of installing high levels of insulation in the roof has spread from France. Practices in Italy may be quite relevant to southern California since Italy is a Mediterranean climate with multiple narrow climate zones.

Pisello et al. find the "indiscriminate diffusion" of high insulation has meant major benefits in winter, yet with summer consequences that have not been evaluated as carefully. When they evaluated this tradeoff, they found that with minimal insulation, their cool roofs lowered the average surface temperature of the roof by more than 10° C (18° F), and the indoor air temperature by more than 3° C (5.4°F).[46] The winter "penalty" was not severe: the reflective roof was about 3°C (5.4° F) colder than the standard roof. Thus, their overall finding is that cooler roofs can have a strong effect in summer in this location in Italy, balanced against a relatively mild negative result in winter.

This ability to reflect large percentages of incoming solar radiation has implications for how hot a home becomes during the day, since typically peak temperature in a house is delayed until after peak radiation, due to thermal transfer from the roofing into the roof space, and in turn from the roof space into the living space. If the roof (attic) space never heats up as much, this could have a positive effect during late afternoon and early evening, which are usually the hottest hours.

In other work that adds to the growing understanding of the interplay between reflected roof radiation, and insulation, Baniassadi et al. studied homes in three different southern California climate zones, neighborhoods chosen for their low tree cover and greater poverty: Chino, Van Nuys, and Long Beach. They found the greatest cooling effect in Long Beach, in homes that had no roof insulation. Peak performance for the cool roof therefore was not found in the hottest location. Nevertheless, they found that since cool roofs are not extremely expensive, they could still be a good tool, even in the hottest zones.

Synnefa et. al applied a white elastomeric coating to the roof of an Athens school. They recorded reductions in summer classroom temperature of 1.5–2ºC (2.7-3.6ºF).[47] Working with a different team on a multi-city simulation of residential buildings, Synnefa et. al found indoor temperatures in Los Angeles homes could be reduced by 2.1ºC (3.8ºF) if the reflectivity of the roof was increased to 0.4. If it were increased more, to 0.65, then peak indoor temperatures could be reduced by 3.1ºC (5.6ºF).[48]

An additional effect of reflecting the sun's photon energy back to the sky is that less is absorbed and reradiated out to the neighborhood. This reduced neighborhood warming (reduced heat island effect) affects people inside their homes in two positive ways. When windows are open, the air coming in from outside is not as warm. Second, to the extent that heat from outside is conducted or radiated into the house, the houses are not warmed as much.

Using a computer simulation, Baniassadi et al. found that the number of hours that people are uncomfortable in a home may be reduced by between 50-155 annually with a cool roof. But if an entire neighborhood is outfitted with cool roofs, the number of reduced hours, per house, may rise to 205.[49]

Rosado and others find that cool roofs make cities cooler in summer. "Replacing a hot roof with a cool roof immediately reduces the flow of thermal radiation into the troposphere ('negative radiative forcing')".[50] However there has been some disagreement on this point. Research by Jacobsen in 2011 posited that in cities, cool roofs could cause a positive feedback loop for warming.[51] The mechanism described is that higher soot or particle levels may absorb reflected radiation and reradiate it as heat. However, in order for this to be a net negative for the climate, one would also have to take into account the reduction in air conditioning use from the cool roof. Zhang et al. found cool roofs reduce ozone formation, but increase particle counts.[52]

Poorly designed cool roofs may also cause discomfort due to glare reflected onto occupants in higher buildings,[53] which the begs the question whether all reflected solar radiation is going back to the sky.

Construction technology evolves. It is evolving particularly fast now, with climate urgency within the architecture and building communities; requirements such as the energy efficiency provisions of California Title 24; and demand for more climate-benign buildings from builders and owners. Roofing is also changing. At present, several types of cool roof are suitable for retrofit situations.

The first is white-colored elastomeric coating applied over an existing roof. According to a 2010 selection guide produced by the Department of Energy, if an existing roof is in good condition, with several years of life remaining, such a coating may be a good option.[54] However, where the roof is visible to the street, the visual effect of the elastomeric white roof may be startling or out of place architecturally. Another type of cool roof is asphalt, in white or cool colors. There are also cool metal roofs. And there are cool roofs made of tile, including concrete tile.

Figure 3. Reflective roofing materials are now available in a wider array of colors and styles, including those consistent with southern California architecture, such as tiles. Photo: Los Angeles Department of Water and Power, "What You Need to Know About LADWP Rebates and Building Code Requirements."

It is evident from this review that there is considerable breadth for what qualifies as a cool roof in the literature. This is probably because scientists studying cool roofs tend to choose materials that are available in their study regions. Roofing materials differ in composition and form around the world. Below, in Table 1, is a sample of reflectivity values taken from the recent literature. For completeness, some values found inside the building energy modeling software BEopt are also included.

Table 1. Breadth of values for reflectivity that qualify as cool roofs found in the literature.

Authors	Reflectivity of cool roof	Reflectivity of existing
L.A. ordinance for roofs > 2:12 slope[55]	0.2	
BEopt: Cool asphalt vs dark asphalt	0.25	0.08
Miller: Cool vs. standard shingles	0.26	0.09
Miller: Brown metal	0.31	0.08

BEopt: Light-colored tile	0.4	
Miller: Brown concrete tile	0.4	0.1
Baniassadi: Cool vs. standard	0.5	0.2
Rosado: Cool concrete vs. asphalt	0.51	0.07
L.A. ordinance roofs < 2:12 slope	0.63	
U.S. Energy Star Label	0.65	
BEopt: White tile	0.7	
BEopt: White metal	0.7	
Pisello: Engineered clay tile vs. traditional tile	0.77	0.19
Piselli: Tile vs. dark asphalt	0.8	0.1
Synnefa: White elastomeric vs. cement gravel	0.89	0.2

The point here is that studies continue to find benefits from cool roofs, even though the cool roofs may vary substantially in their reflectivity. The range that researchers have studied, shown in Table 1, is from 0.26 for the reflectivity used in Miller, to 0.89 for the roof studied by Synnefa, a spread that encompasses more than half of incident solar radiation.

Results.

Results of the attempted simulation are found in the discussion.

Table 2 below collects the results published in the literature on any of the four retrofits where indoor temperature reductions were noted. (There were no studies that indicated an increase in temperature.) The third column indicates the amount of temperature reduction in degrees. The column titled "Notes" specifies the type of metric the researchers selected, for example peak temperature or average temperature reduction.

Table 2. Temperature reductions found in the literature from any of the four retrofits.

Author	Retrofit Type	Indoor ° C reduction	Indoor °F reduction	Notes
Pisello	Roof	>3° C	>5.4° F	Average ° reduction

Synnefa, Saliari	Roof	1-2.7°C	1.8-4.9°F	Average ° reduction
Synnefa, Saliari	Roof	1.5-2°C	2.7-3.6°F	Average ° reduction in summer
Synnefa, Santamouris	Roof	2.1°C	3.8°F	Decrease in peak in L.A. ° with 0.4 reflec. roof
Synnefa, Santamouris	Roof	3.1°C	5.6°F	Decrease in peak in L.A. ° with 0.65 reflec. roof
Kolokotsa[56]	Roof	1.5°C	2.7°F	Average daily reduction ° in summer
Pereira	Window film	4.8° C	8.6° F	Peak reduction °, July day, indoor film
Pereira	Window film	8.9° C	16° F	Peak reduction °, July day, outdoor film
Pereira	Window film	2.8° C	5° F	Average ° reduction, July days, indoor film
Pereira	Window film	4.1° C	7.4° F	Average ° reduction, July days, outdoor film
Moretti	Window film	2-3° C	3.6–5.4° F	Not specified
Kumar	Overhang	2.5–4.5°C	4.5–8.1° F	Not specified
Pastore	Trees	3.4 ° C	6.1°F	Reductions up to this amount found
McPherson	Trees	3.25° C	5.85°F	Reduction in peak ° with east-planted tree
McPherson	Trees	7° C	12.5°F	Reduction in ° from east-planted tree, at 1 pm
McPherson	Trees	3.5° C	6.3° F	Reduction in peak ° with west-planted tree
McPherson	Trees	6.5°C	11.7°F	Reduction in ° from west-planted tree, at 6 pm
		% Δ Hours		
Porritt	Overhang	15-16%		Reduction in uncomfortable hours
Porritt	Overhang	28%		Reduction in uncomfortable hours
Dabaieh	Roof	53%		Reduction in uncomfortable hours in summer
Baniassadi	Roof	105		Reduction in uncomfortable hours (not %)

Discussion.

The evidence is adequate that well-designed cooling retrofits can significantly reduce temperature in homes. By combining these measures on a home, it is very likely one will achieve several degrees of peak cooling. The cooling is sufficient in some Los Angeles locations to delay or avoid the need for air conditioning under current and near-term climate changes. In hotter areas of the city, these measures may not be sufficient to lower temperatures enough during heat waves to protect the thermal health of occupants in the current climate regime.

Limitations.

An attempt to model indoor air temperature applying the four retrofits of interest was made using the software BEopt. A model of a 90-year-old home in the 90033 zip code, corresponding to the Boyle Heights neighborhood of Los Angeles, facing northeast, with a footprint of 1500 ft^2, uninsulated, was created.

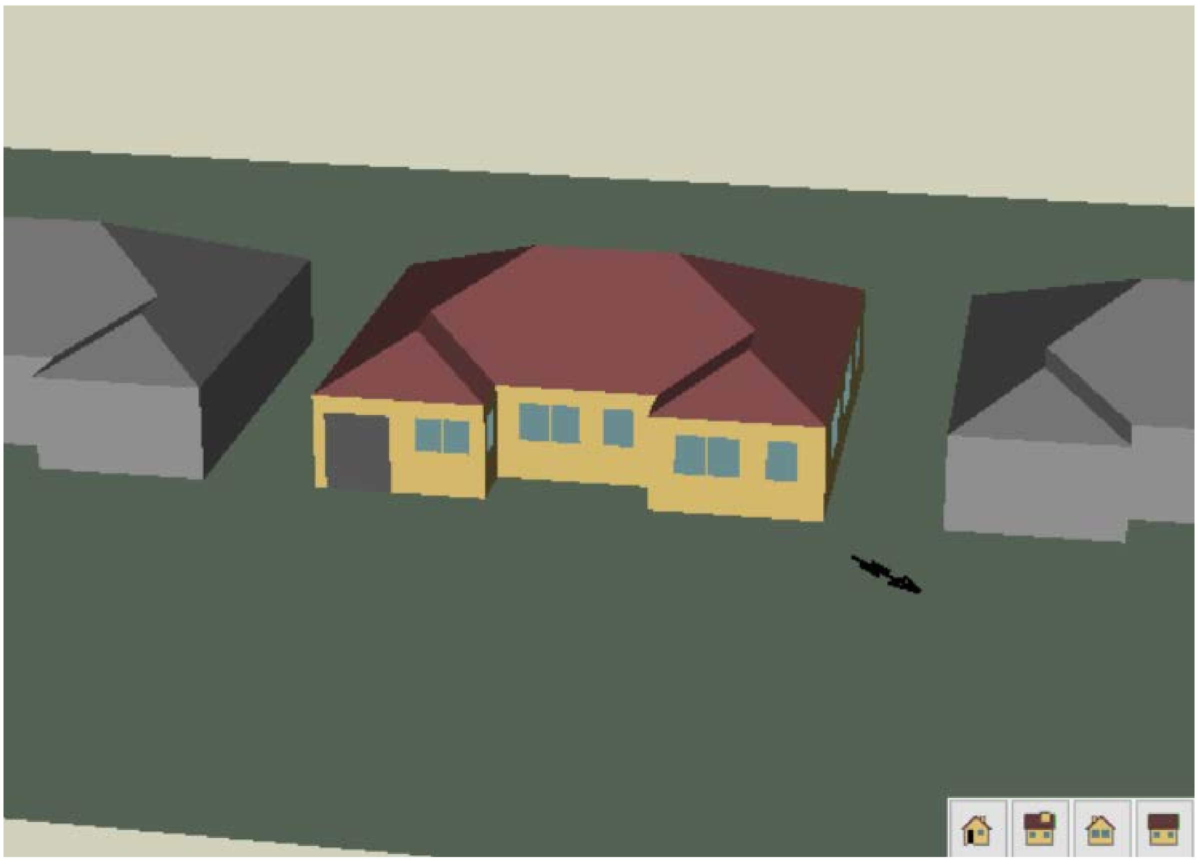

Figure 4. Model of an unretrofited 1920s Los Angeles house created in NREL software BEopt. The building has a below-ground foundation that does not show in the photo.

Simulations comparing its original condition, which is shown, with the retrofitted condition were run, as well as parametric analyses. Results showed anomalies. In both the base and design cases, the structure reported indoor temperatures that exceeded outdoor temperatures at all hours of the day on all days of the year.

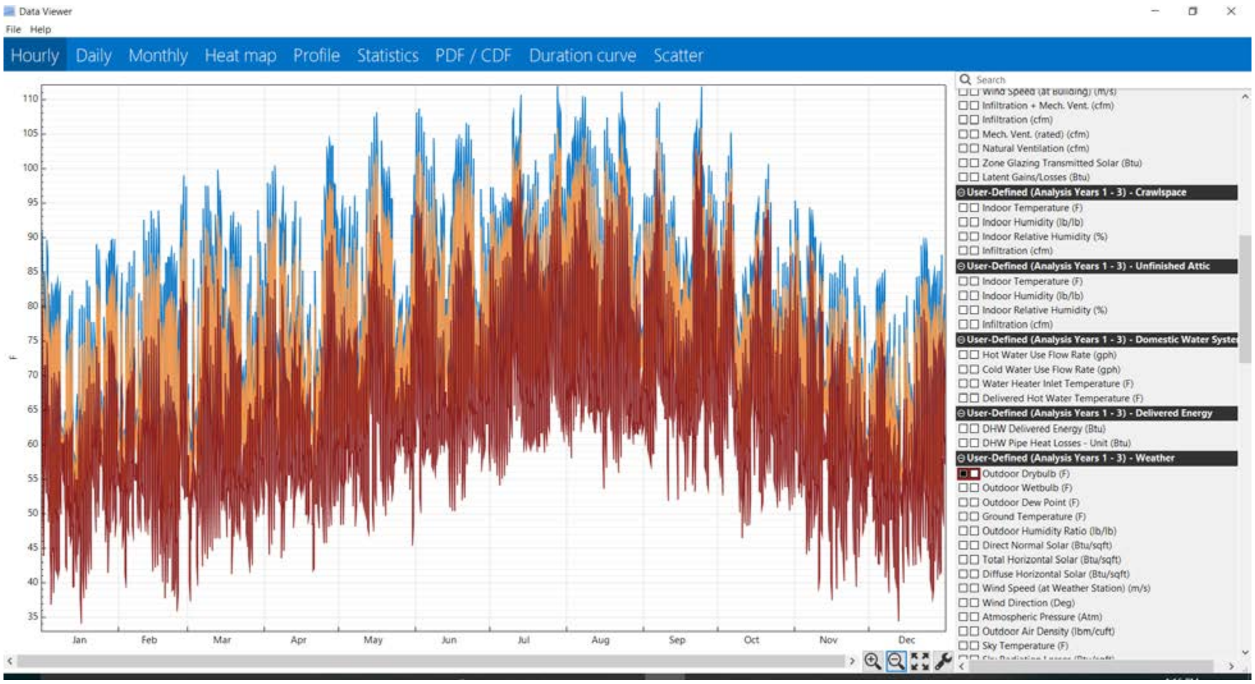

Figure 5. Anomalous results obtained from BEopt simulation. Indoor temperatures in the base case are blue. Indoor temperatures with the package of retrofits applied are in yellow-orange. Outdoor temperatures are in dark red. A reduction in temperatures is shown when the cooling measures are applied. However, it is hotter indoors than outdoors each day of the year, including winter, during most hours. Therefore no analysis is performed.

This researcher contacted the software author at the National Renewable Energy Laboratory (NREL). Scott Horowitz suggested a change to the underlying Python code in which BEopt is scripted. Horowitz reported BEopt contains an error in its foundation heat transfer model.

The proposed fix was made in the source code and the simulation rerun. In the base case, the results were now significantly different. But the design case continued to generate significant temperature anomalies, such that no results could be drawn and the simulation had to be abandoned. BEopt software continues to be available to persons for download without a warning, and professionals may be using this software to make important HVAC specifications and purchases. NREL says it will be releasing a new version of BEopt at some time in the future with the bug fixed.

Suggestion for Policy.

The way that heat enters a building is startlingly complex. There is no formula that captures it. The heat gain depends on, among others: the direction the home faces; its latitude; the climate; proximity of nearby buildings; exterior coatings; insulation; glazed area; window material and window construction (for example single pane clear glass); the presence and extension of roof eaves; the presence of window awnings or overhangs; roofing material; the presence and location of trees and whether these are deciduous.[57]

Yet this complexity should not deter efforts to address overheated housing in Los Angeles. Low performance, non-air conditioned buildings have the greatest potential for improvements in thermal comfort and energy efficiency.[58] As cited in the introduction, there is a clear and urgent need for cooling innovation.

A proper team of experts could develop a palette or tool. This tool could be used to evaluate and select tailored suites of residential retrofits for individual houses. Reflecting the complexity of heat gain, this team should be composed, at a minimum of:

- One or more building professionals with extensive experience in the renovation of older residential buildings
- An energy efficiency specialist whose experience and orientation is towards cooling, rather than insulation and heating, and who is steeped in the West, not the East or Midwest, where needs are different.
- A physicist or engineer with deep knowledge of principles of thermal and light transfer through glass and roofing materials.
- A landscape designer with experience with native and Southwestern trees used to avoid

summer heat gain while preserving winter heat gain.

It would be useful for Los Angeles, both the city and county, to know how many people are experiencing heat stress. In addition to the California Heat Assessment Tool mentioned above, the organization TreePeople is currently contracting for a vulnerability study that will be accurate down to the census tract level. The recent OurCounty sustainability plan calls for a countywide climate vulnerability assessment that prioritizes public health preparedness, emergency preparedness and community resiliency. Research is also underway to determine how much of Los Angeles County land area is paved or covered by heat-trapping surfaces.

Weatherization programs already exist. In Southern California, these often include: energy efficient lighting and windows, improved existing insulation, ventilation, and duct-sealing.[59]

It is the author's view that a more comprehensive approach, one that focuses on the increasing threat of heat stress, is needed. Whether this approach is de novo or expands on existing weatherization programs should depend on scrutiny of the current programs and how well they achieve their goals. Recent research by Graff Zivin and Novan examines homes in rural San Diego County and finds that retrofits provided under the Weatherization Assistance Program did not, in fact, reduce energy use.[60] They found routine overstating of energy savings. Some they attributed to the DEER software (Database of Energy Efficient Resources) on which estimates are based. DEER uses averages to estimate savings per retrofit, not measurements.

This Weatherization Assistance Program is the largest residential energy efficiency program in the United States. This federal government provides grants to the states and to 740 local agencies, governments and non-profits. These organizations provide screening, audits and work on the ground.[61] It has provided weatherization to more than 7 million low-income households since 1976,[62] at a cost of $257 million.

Certain individual cooling retrofits are available in Los Angeles, and these are examined below. However, what is lacking is comprehensive evaluation for the best suite of options that might cool a building. What is available is more piecemeal. Nor are some measures, such as overhangs, offered through existing programs. A new, more complete evaluation should also integrate recent research and thinking, for example, the reevaluation of the role of ceiling insulation.

Cooling retrofits are not always available to owners who do not currently have air conditioning, because cost benefit analyses often look at energy savings, rather than at human health and comfort. Logic dictates that if a household does not have air conditioning, then it cannot demonstrate energy savings from cooling retrofits, even if the occupants are at risk.

Reflective roofs.

Cool roofing has been required on new residences in the city of Los Angeles since 2014. Large remodels and additions also require it. The County of Los Angeles followed the city's lead five years later. On existing housing that is not undergoing major renovation, there is no requirement.

The Los Angeles Department of Water and Power carries out a cool roof Consumer Rebate Program. An owner who pays for a new roof can recover $0.20 or $0.30 per square foot, depending on how well the chosen product reflects energy, as determined by the Cool Roof Rating Council.

At the higher reimbursement rate, this amounts to a $500 rebate on an average-size roof. While this may be a meaningful rebate, it would only be available to those who can afford approximately ten times this amount for a typical roof installation. Indeed, the program is not intended to aid the homeowner in the installation of a roof, but rather to defray any difference in cost between a traditional and a cool roof. [63] The LADWP has paid out 2,200 cool roof rebates since 2010, covering 7 million square feet of rooftop.[64]

With respect to elastomeric roof coating, the Environmental Protection Agency estimates a typical 1,500 ft^2 installation at between $1,600 and $6,500, or $0.75 to $3.00 per square foot.[65]

One team in Los Angeles is evaluating roofs for comprehensive retrofits that are both reflective and solarized. These “Climate-ready roofs” are installed by a partnership among the groups Grid Alternatives, Climate Resolve and Habitat for Humanity.

Finally, any effort to address cooling should note one recent study performed by the California Energy Commission that found reflective walls could be as important as reflective roofs. [66]

Trees.

City Plants is the authority for shade tree planting in Los Angeles. It is a non-profit that evolved out of several efforts, including the Million Tree campaign of the mid-2000s and now runs a public private partnership between the city and six tree planting non-profits. It plants 18,300 trees per year in yards, and others in public spaces.

It costs $60 for one 5-gallon tree. This includes stakes, ties, fertilizer, maintenance while in the nursery, and delivery.[67] Watering the tree during a 3 to 5-year period of establishment costs approximately $10 per year.

Currently, the limited funding for City Plants supports a staff of three. This funding comes from utilities, obligated under energy efficiency requirements in law AB 2021.

In 2003, McPherson found that only 42 percent of available identified sites for planting trees in California cities were filled. If 50 million trees were planted near homes to shade east and west walls, he reported, 20 percent of those vacant sites would be filled. [68] Other teams have found several concerning urban tree trends: Larger homes are edging out available spaces for trees. A recent report on Los Angeles County's urban forest found the region to be in a critical period "for potentially catastrophic tree canopy cover loss."[69] The correlation between the wealth of a neighborhood and tree cover is also becoming stronger.[70]

McPherson has long advocated that the California Energy Commission, and California homebuilders, make shade tree planting mandatory in California's comprehensive Title 24 Energy Efficiency Standards for Residential Buildings. This code is revised every three years per statute. Trees are absent from the 2019 revision.

Window Films.

Property owners in both of Los Angeles' utility service areas may obtain loans to cover the installation of window films, through a partnership between Los Angeles Department of Water and Power and Southern California Gas, called the Residential Energy Efficiency Loan (REEL) program.

Window films merit attention because they are less disruptive than replacing windows, which includes not only the significant capital cost of the window units, but opening the walls, repairing stucco or other siding, repairing drywall and mud on the interior, paint prep and painting inside and outside.

One source estimated the installation cost for solar films at $5-6 per square foot. For the popular films in 3M's Prestige series, the cost could be closer to $10-12 per square foot. For 100 square feet of windows, this range would be roughly $500 to $1200. Not all the windows in a home need be treated. One would not apply films for the purpose of cooling to north-facing glass, for example.

Overhangs.

As noted, overhangs are still not well known outside the architectural and green building communities. Currently prices for pre-made solar window overhangs run from approximately $125 to $500 per awning, without installation. Installation may be accomplished by anyone with carpentry skills. Awnings may also be fabricated onsite out of wood with slats engineered for the correct latitude and sun angle blocking.

Further Steps.

Los Angeles should consider a GIS-based program that fields calls and referrals from and about residents suffering with heat stress. These households should have access to a single point of contact with which to work on healthy cool housing retrofits. What should be avoided is separate contacts each for traditional weatherization, utility efficiency programs, and new cooling retrofits. The goal should be for all people experiencing overheating to have the problem addressed. The California public utilities code §382 already provides that as of the end of 2020, all low-income people, including renters, must have the opportunity to participate in efficiency programs.

Such a combination of health-based cooling retrofits, plus traditional weatherization, would not be novel. In Kansas City, Missouri, the housing energy efficiency program worked together with a children's environmental health center to train its energy auditors. The new Healthy Homes Incentive Program in Allegheny County, Pennsylvania promotes home energy upgrades that improve indoor air quality. Washington State's Matchmaker Program matches state money with federal weatherization and utility programs combining efficiency and health measures.[71]

A first step is to move beyond mere energy cost-benefit calculations, which sometimes fail to account for health considerations as a benefit. There is a term for this: "non-energy impacts." California and some other states already have a way of quantifying these non-energy impacts. California incorporates these into a metric called "total resource cost," (TRC). The state also incorporates non-energy benefits into the Energy Savings Assistance Program Cost Effectiveness Test (ESACET), but this is for information purposes only.

Allowing homeowners to find all their home improvement options for health and for energy in a single place would not be new, either. Massachusetts, New Jersey, Wisconsin, and New York provide this one-stop shop model. The New Jersey Board of Public Utilities Comfort Partners Program began in 1999. It coordinates funds from seven utilities to provide a single program to customers. Ohio also combines multiple utility, federal and state funds into a single Home Weatherization Assistance Program.

Since 2014 globally, buildings have consumed 30 percent of all primary energy.[72] The number of air conditioned buildings and the square footage that is air conditioned rose 71 percent in the 20 years between 1994 and 2014.[73] The scientific consensus as represented by the Intergovernmental Panel on Climate Change Special Report 15 is that not more than 340 gigatons of carbon dioxide may be released into the atmosphere beginning in 2020, to preserve a 67 percent chance of non-catastrophic climate disruption (1.5°C increase since pre-industrial times). This cannot be accomplished on the current air conditioning path, in which demand could increase by 41–87 percent between 2020 and 2060, and that is under an RCP 2.6 scenario.[74]

This review demonstrates that passive cooling retrofits have been under appreciated as a possible remedy for heat stress, and an alternative to air conditioning in some older housing.

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